

SAR Interferometry Applied to Mt. Etna: Magmatic and Volcano Structural Interactions

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California Institute of Technology

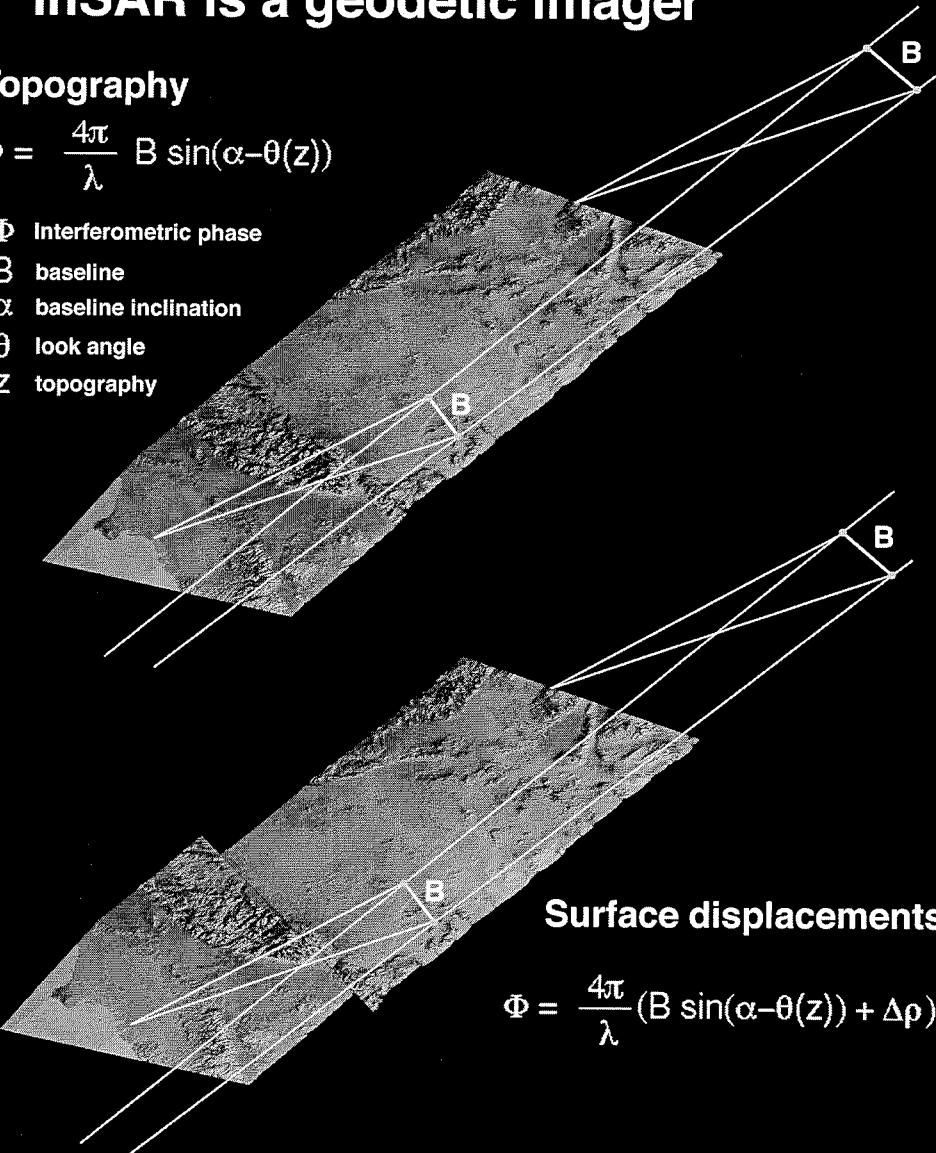
Satellite radar interferometry

InSAR is a geodetic imager

Topography

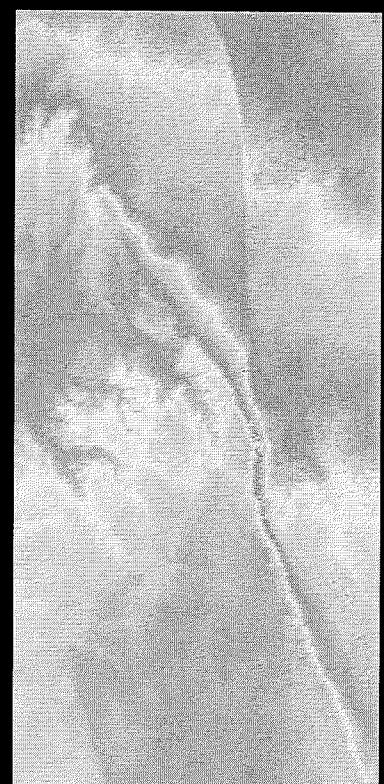
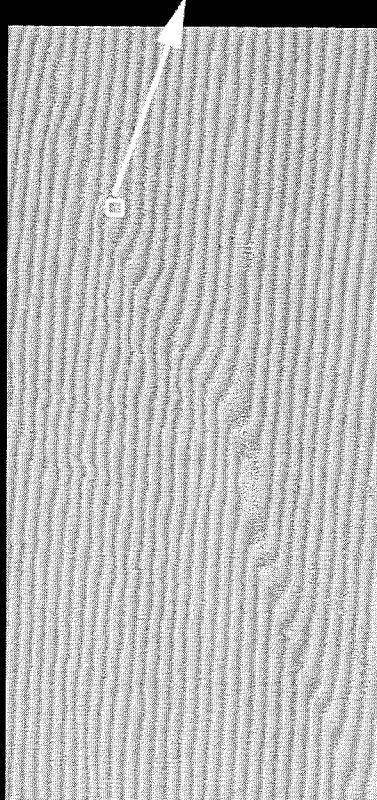
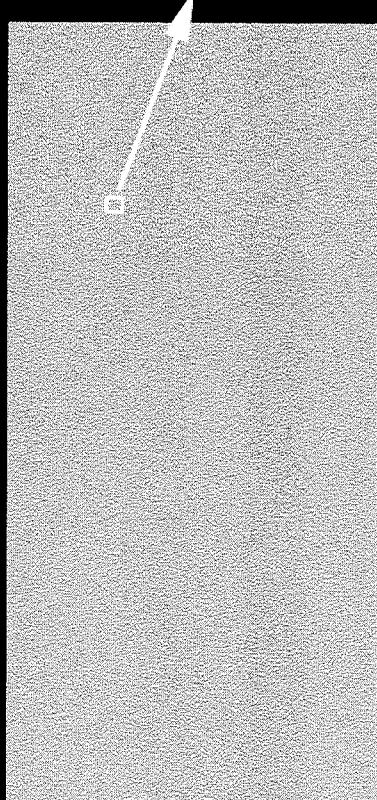
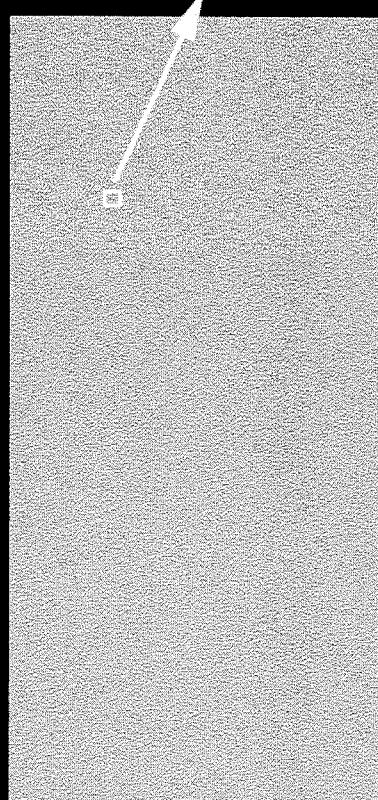
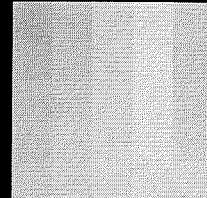
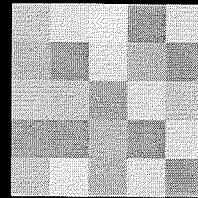
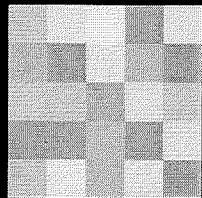
$$\Phi = \frac{4\pi}{\lambda} B \sin(\alpha - \theta(z))$$

- Φ Interferometric phase
- B baseline
- α baseline inclination
- θ look angle
- Z topography



SAR interferometry

coherent phase



phase 1

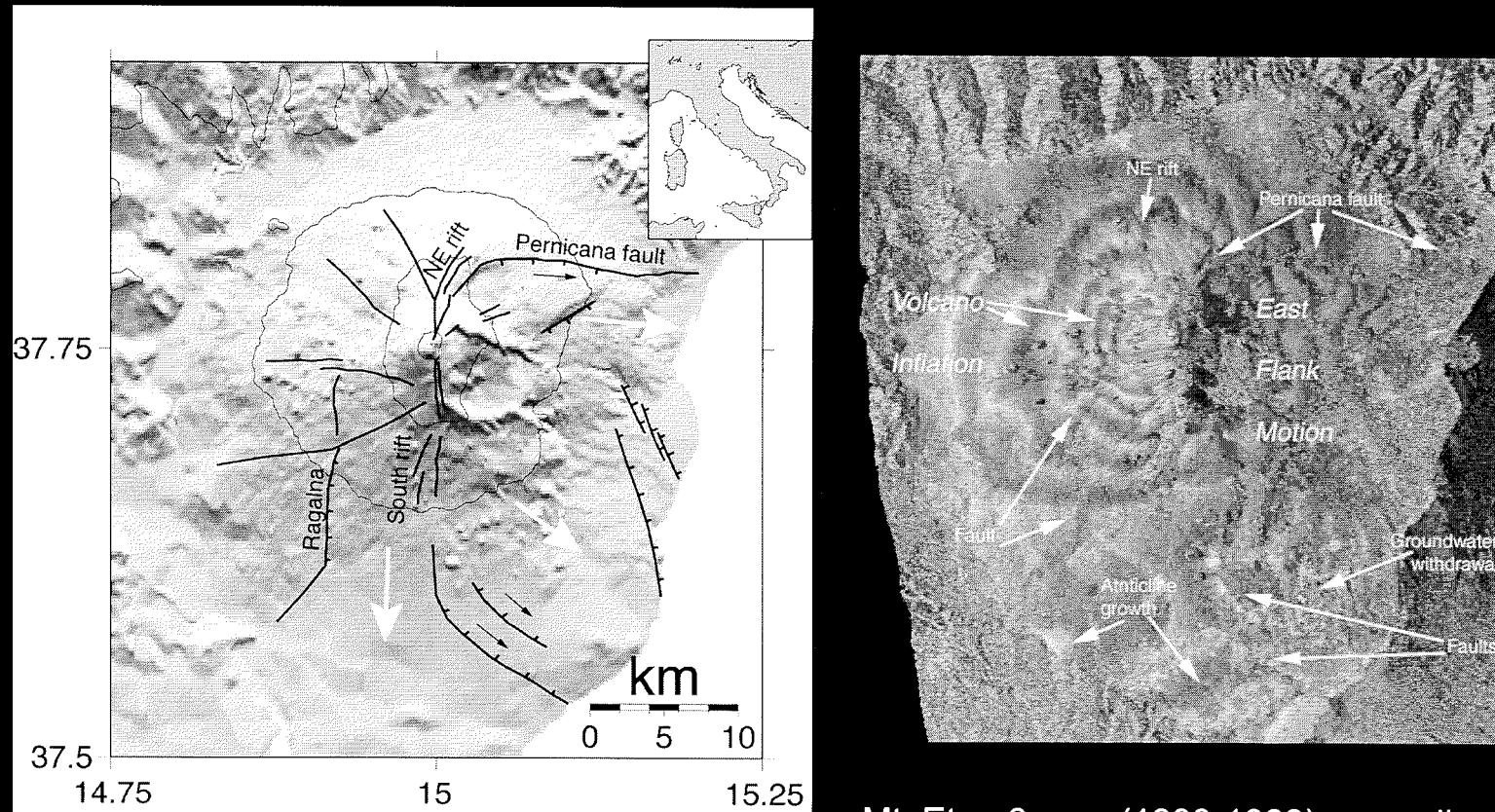
phase 2

= interferometric
phase

flat interferometric
phase

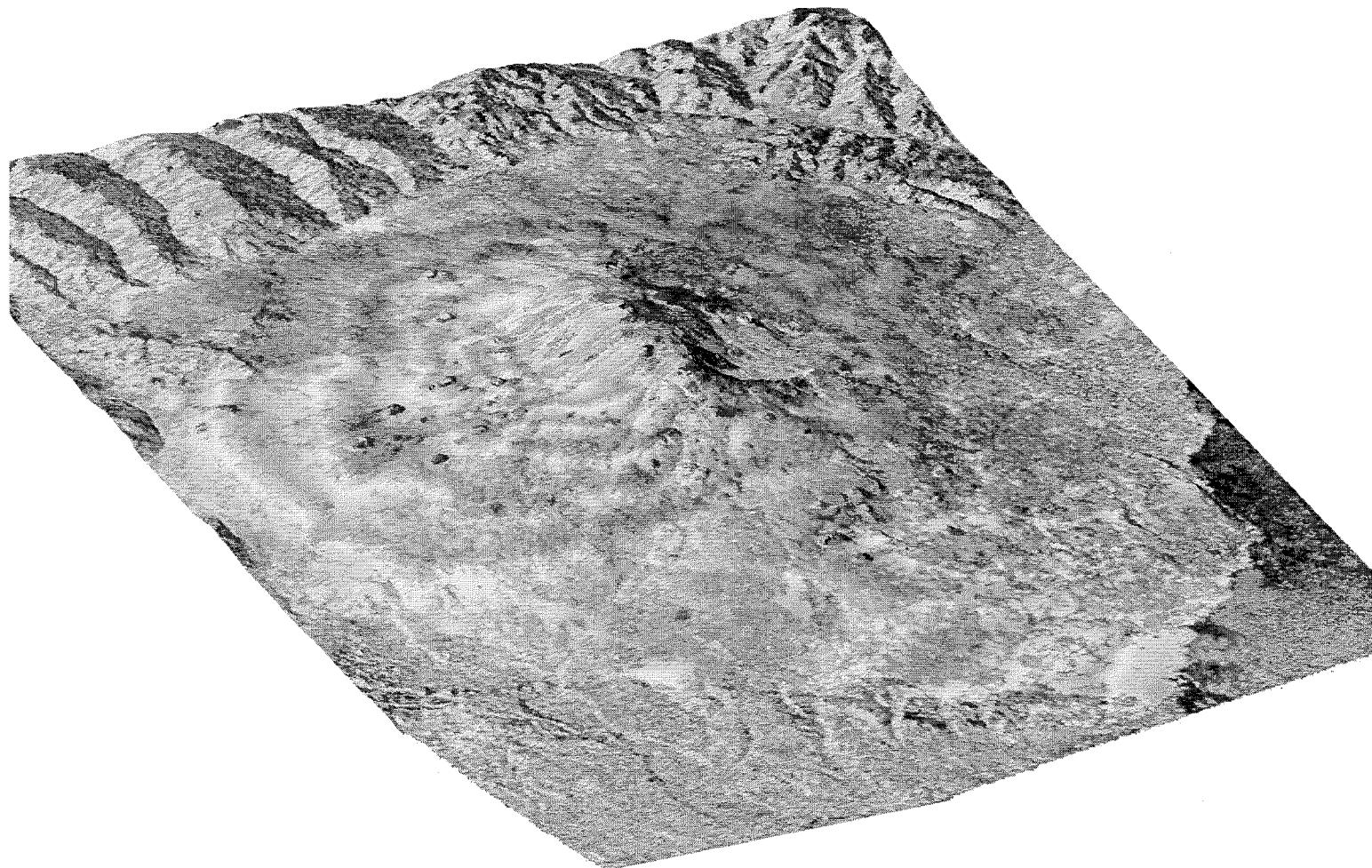
GP, JPL, 1998

Mt. Etna rift and fault systems



Mt. Etna 6 year (1993-1999) ascending
ERS SAR interferogram

Mt. Etna: magmatic deformation and structural motion



~2 year interferograms: Inflation...1993 -1995

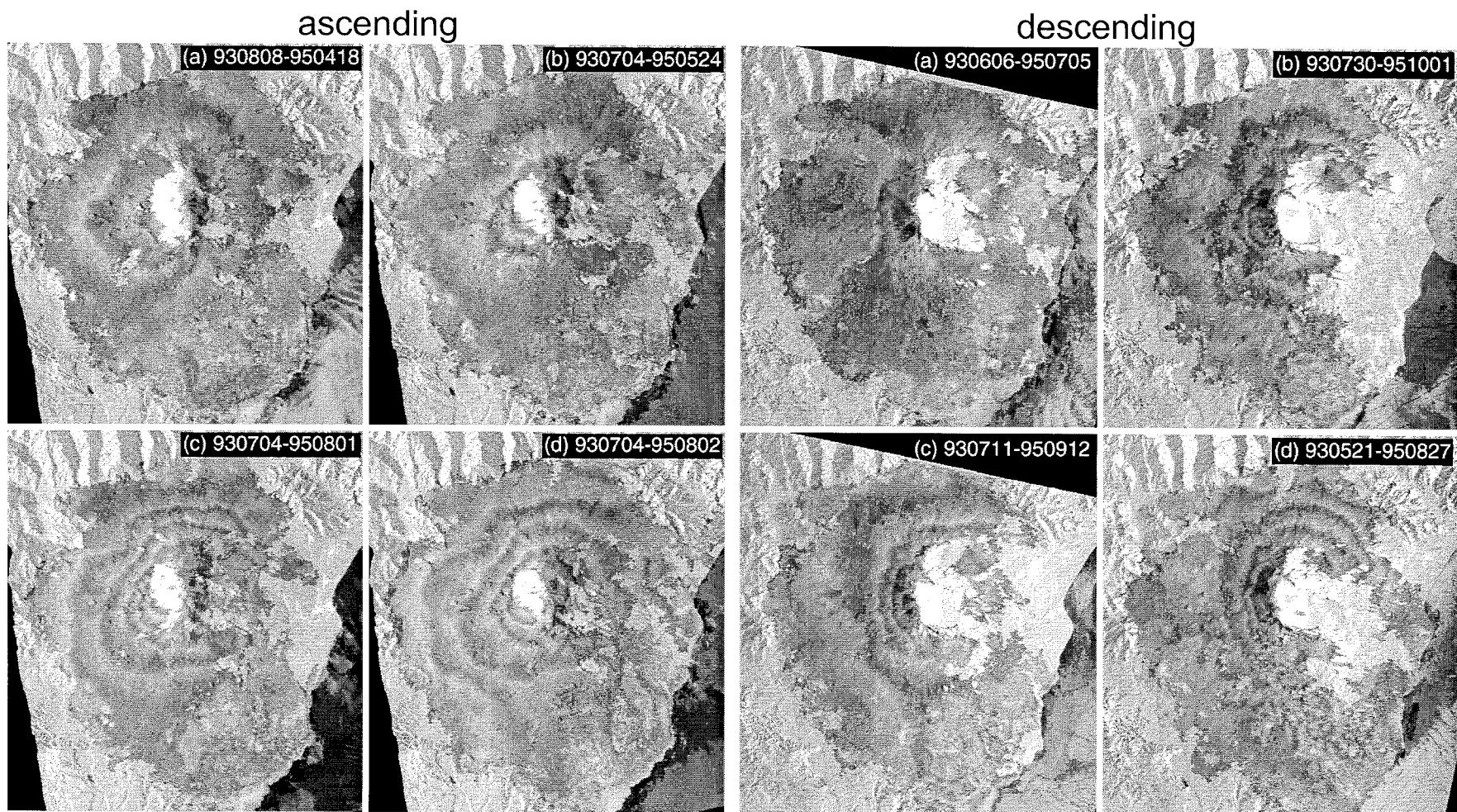
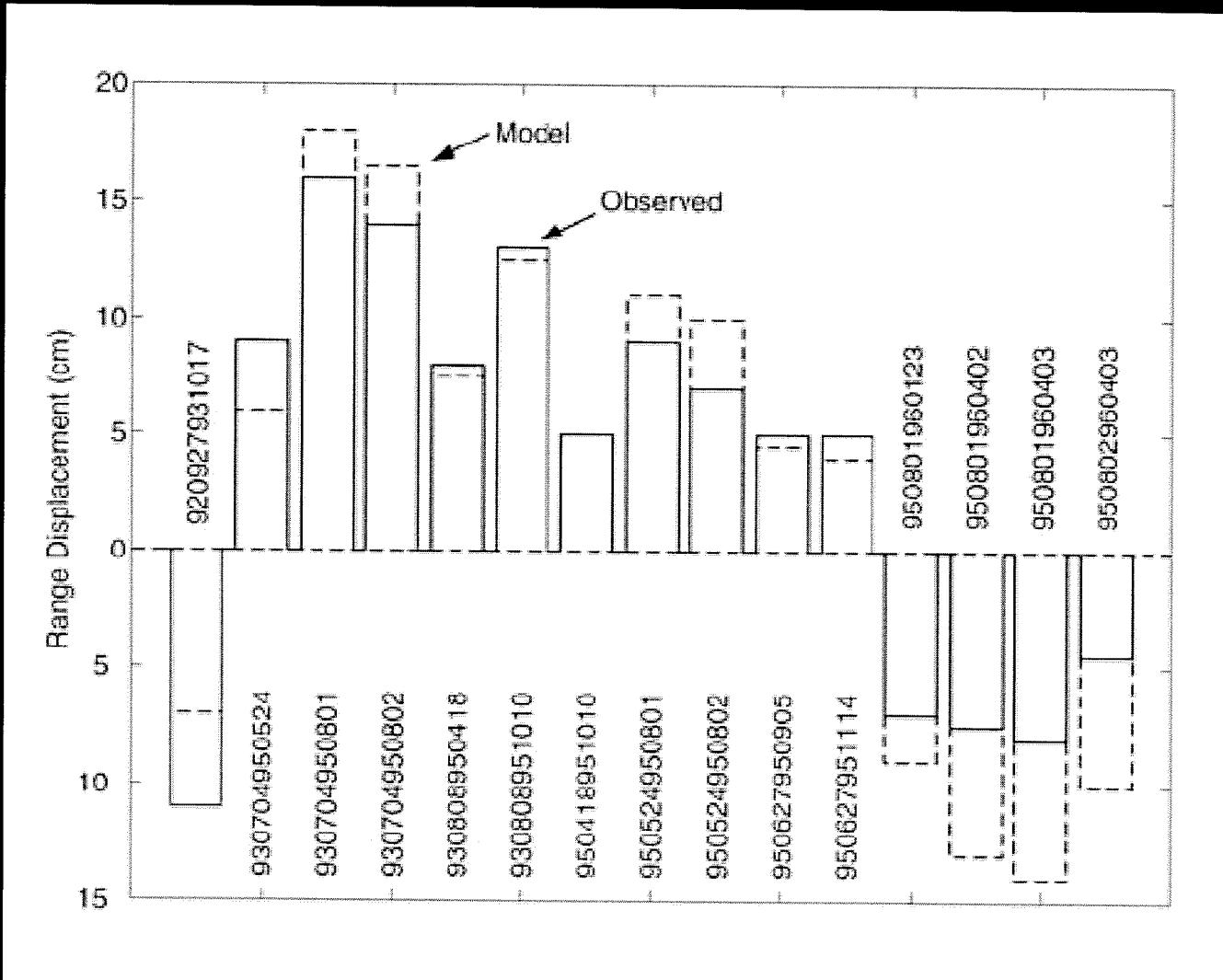


Plate 2

Atmospheric corrections (following Delacourt et al., 1998)



So, looking at lots of data suggests that most of what we see is surface deformation.

How to explain the different fringe patterns seen over similar time periods?

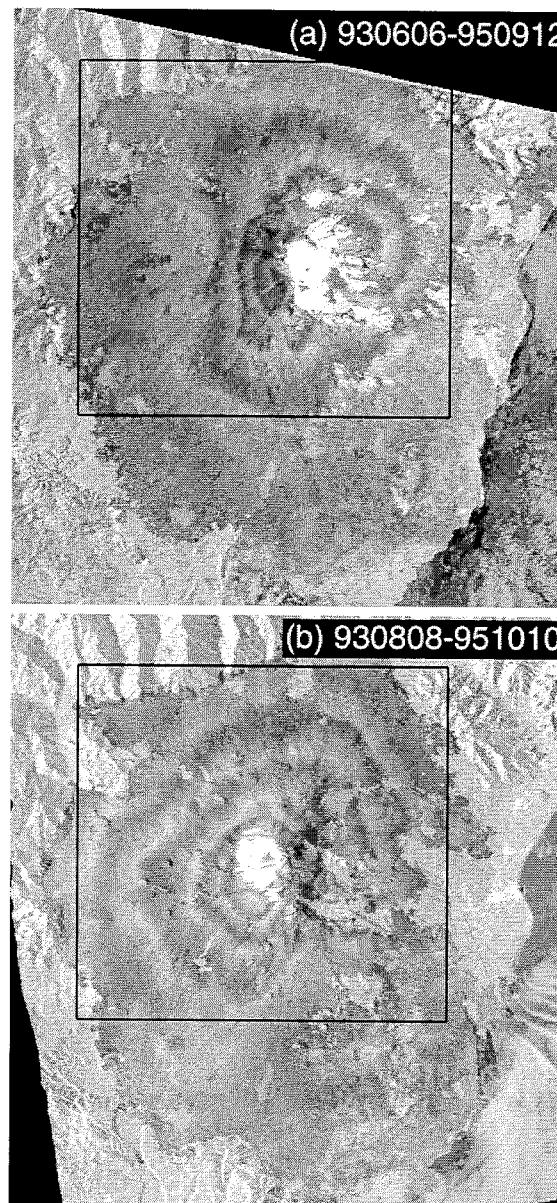
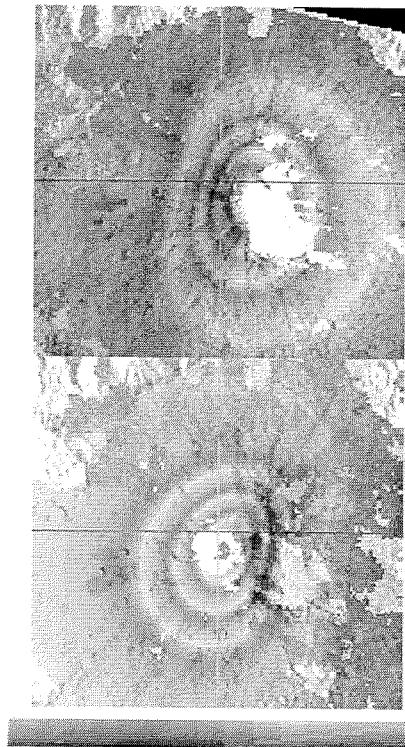


Plate 3

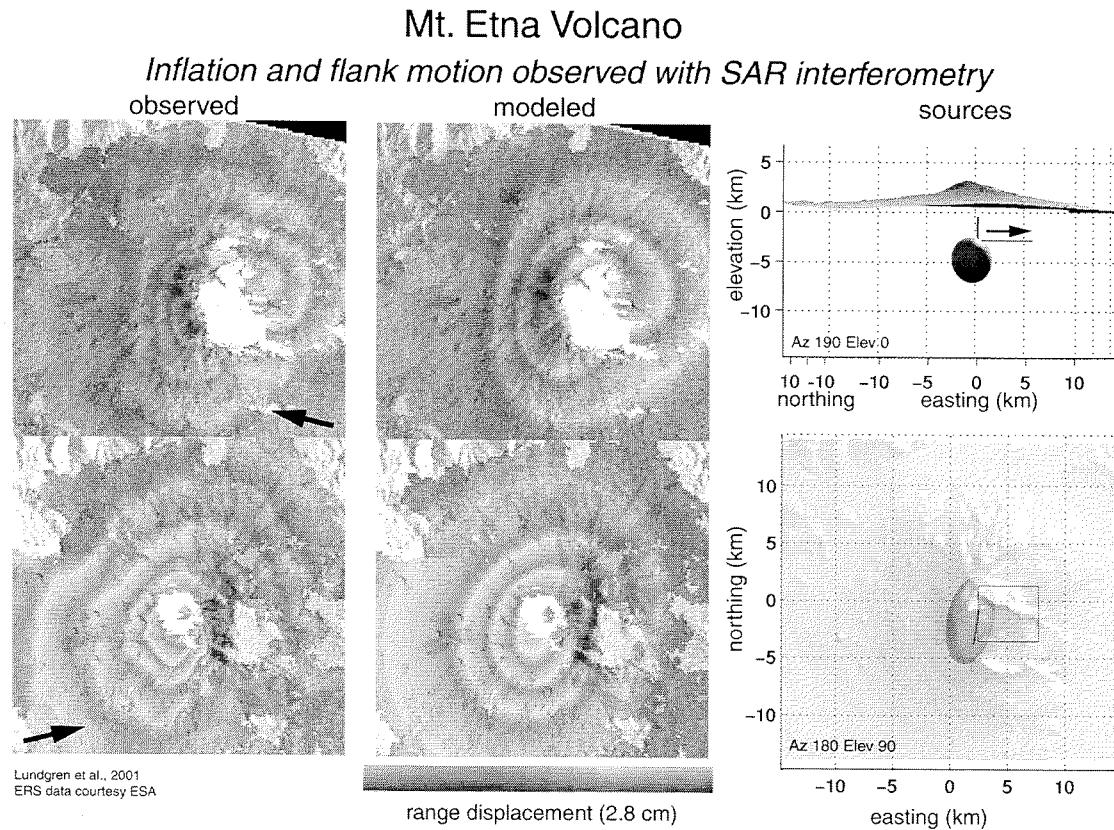


2.8 cm range displacement

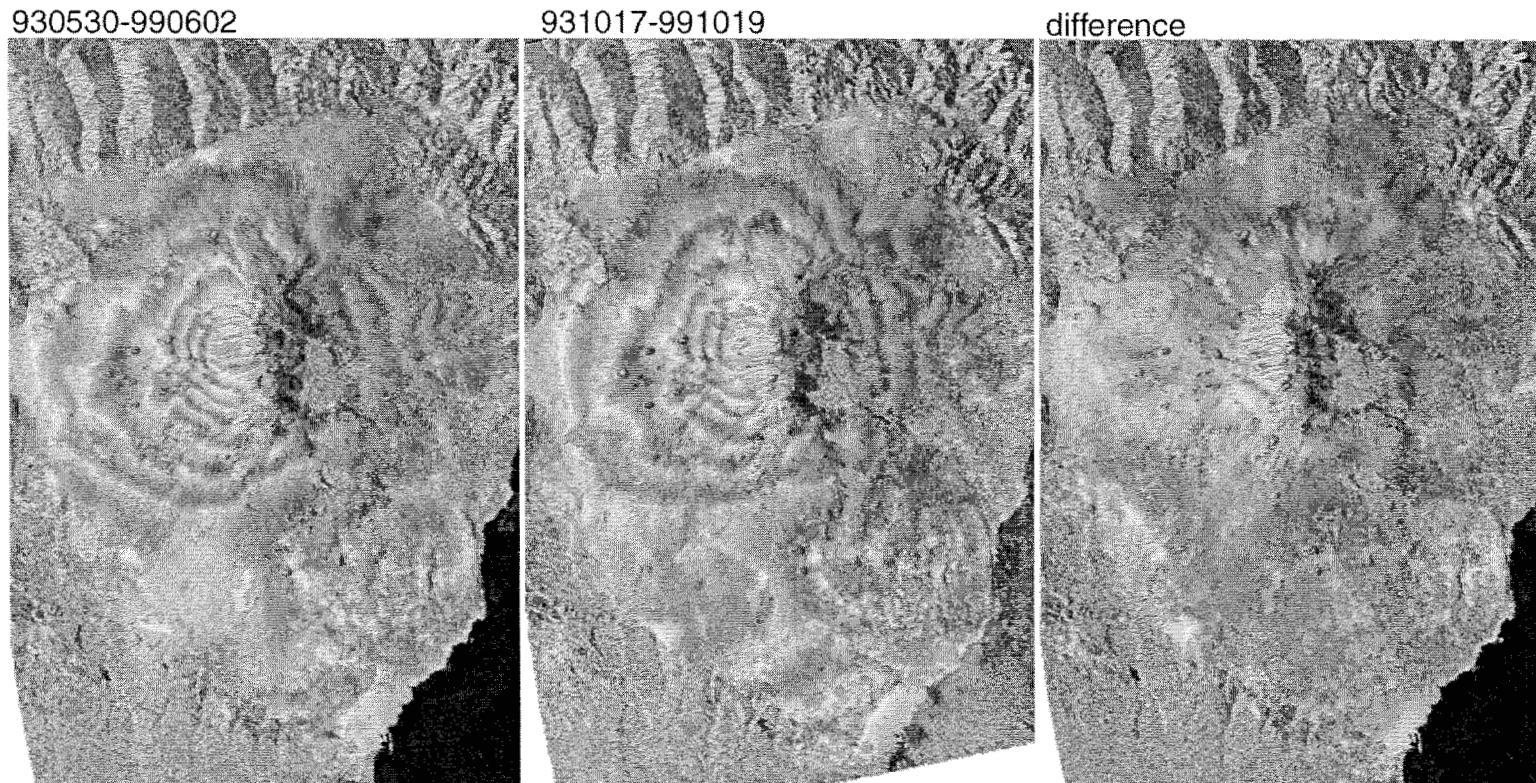
Plate 7

Spheroidal pressure source can be part of the answer...

Consider adding motion of an east flank wedge...



1993-1999 six years of inflation and flank movement

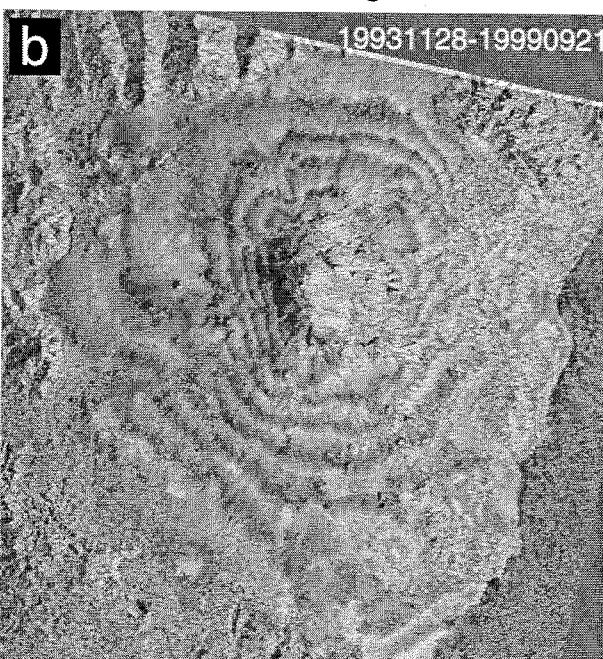


ESA ERS SAR interferograms. Track 129. 2.8 cm/color cycle

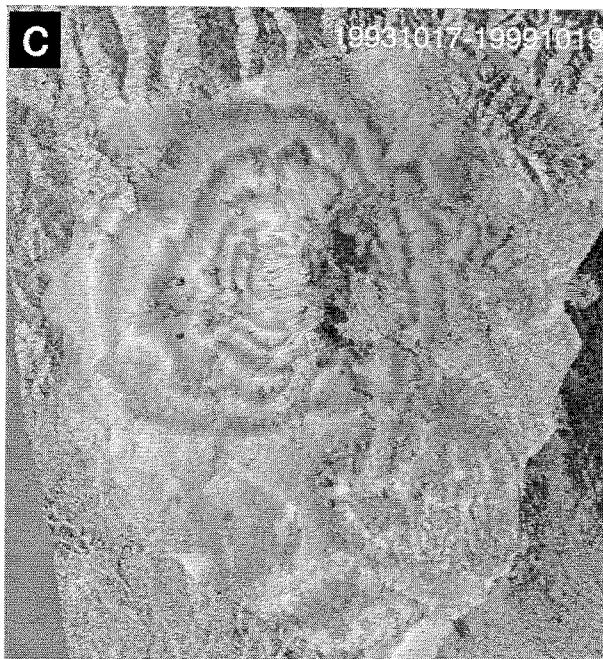
ascending



descending



19931017-19991019



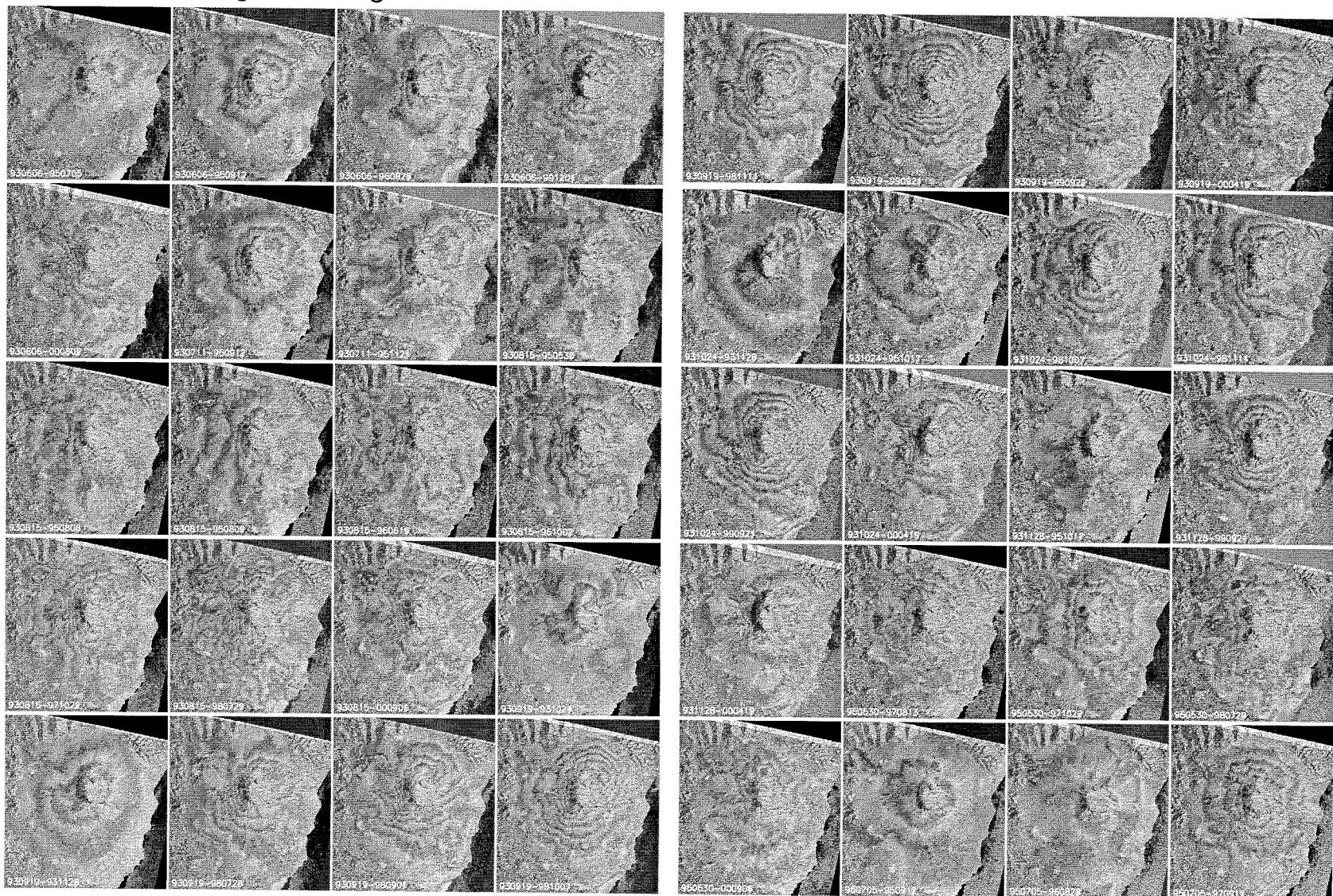
19931024-19990921



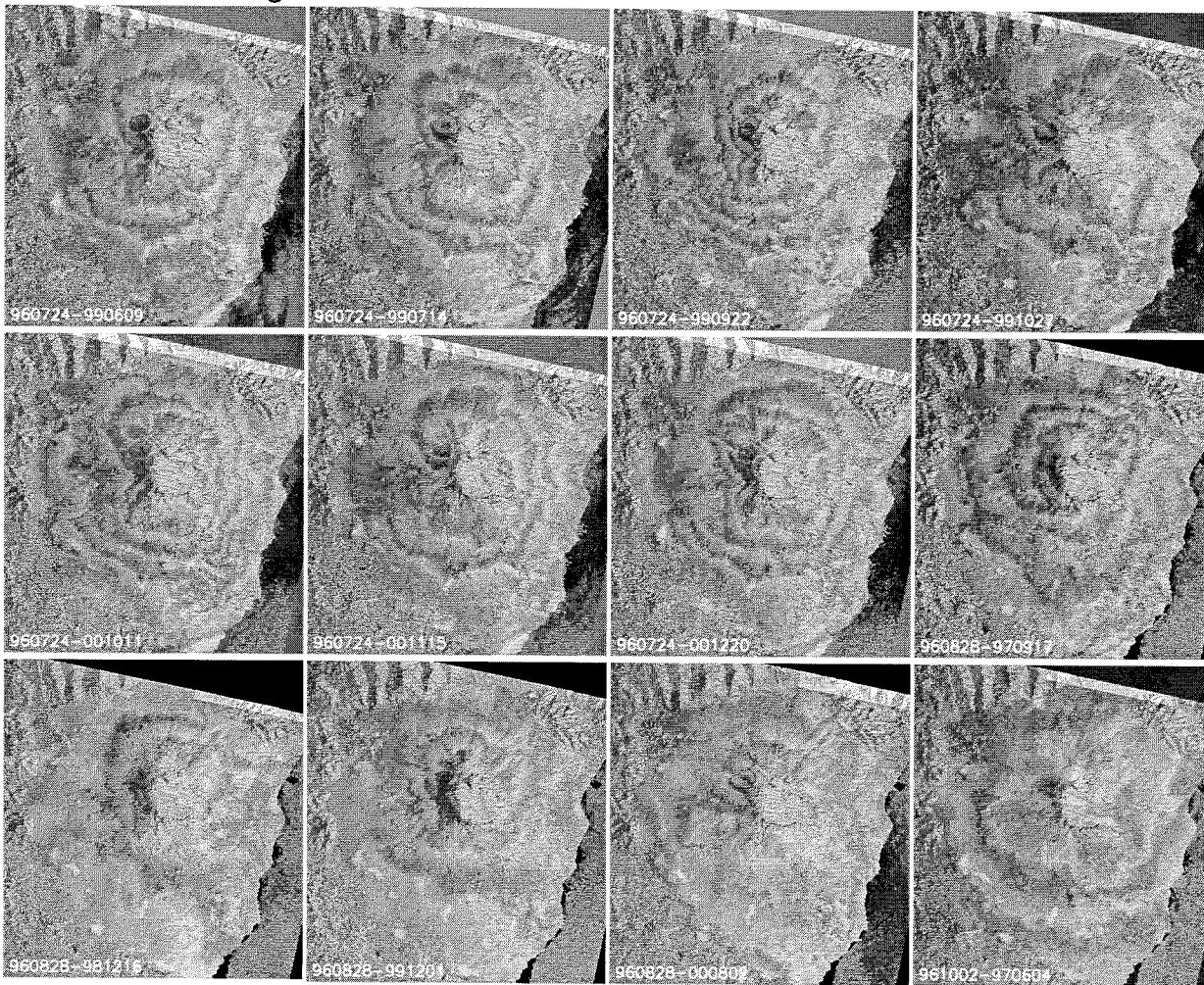
Ascending interferograms 1993 +



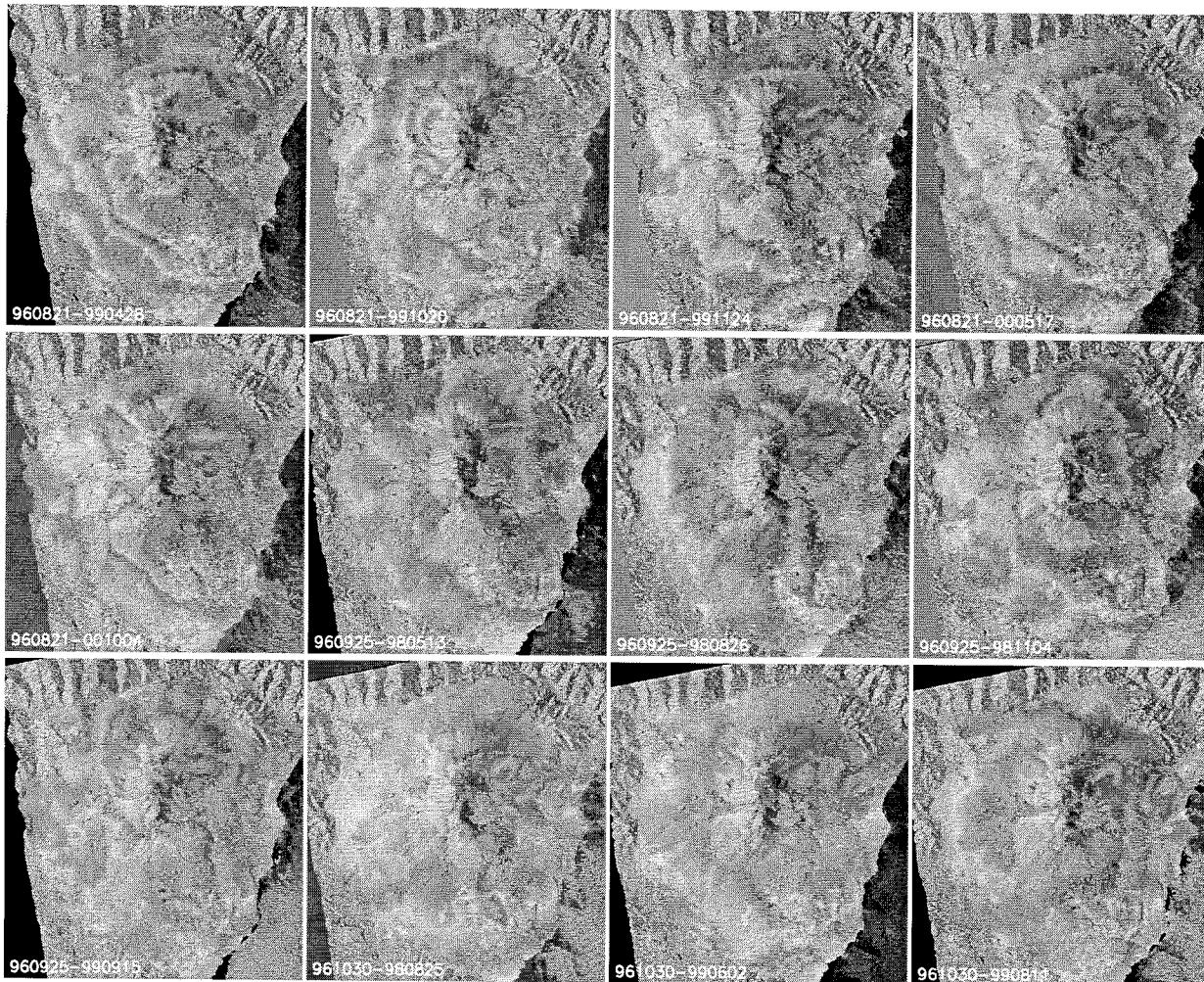
Descending interferograms 1993 +



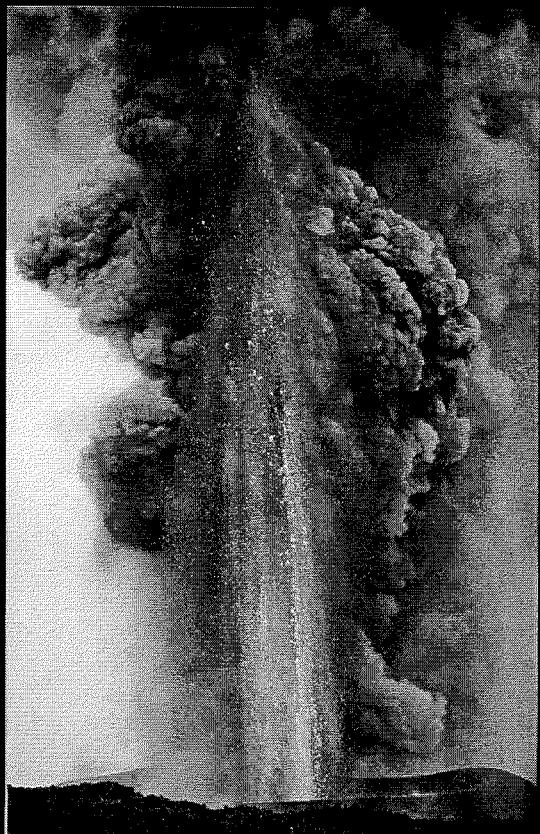
Descending 1996+



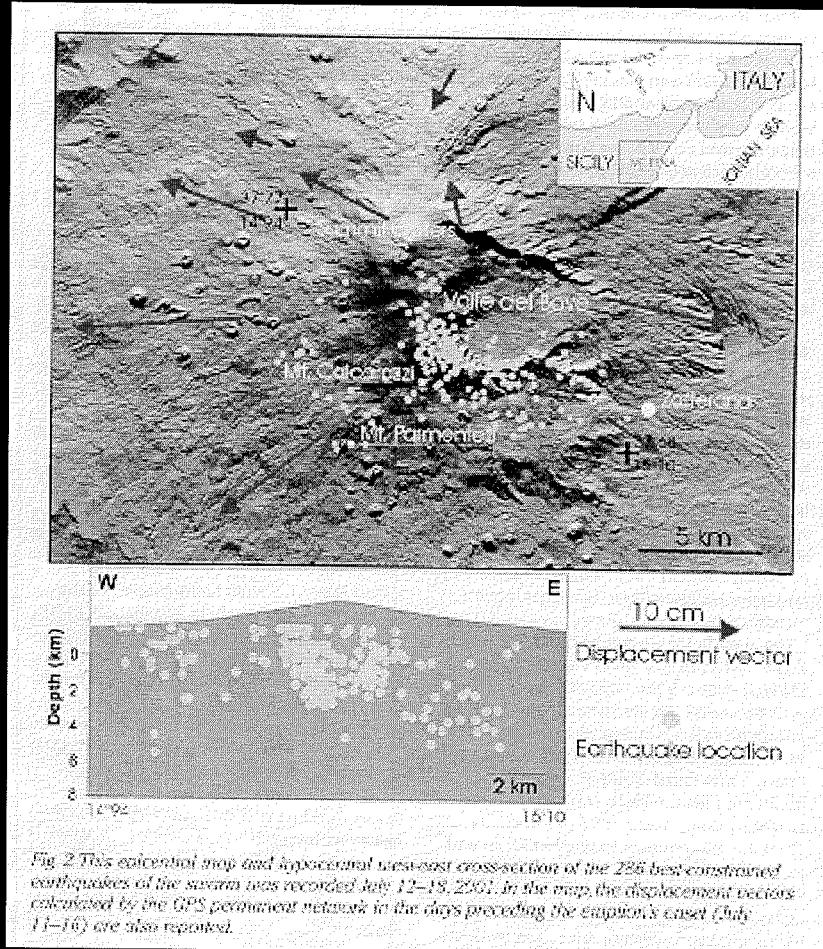
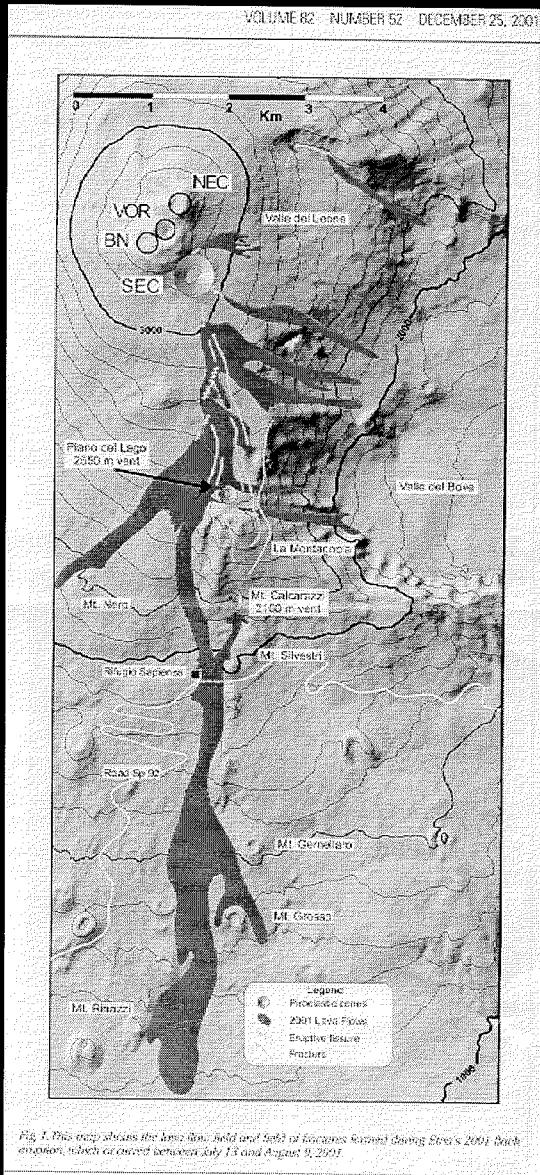
Ascending 1996 +



A New Mode of Volcanic Dike-fault Interaction Observed with SAR Interferometry for the 2001 Eruption of Mt. Etna

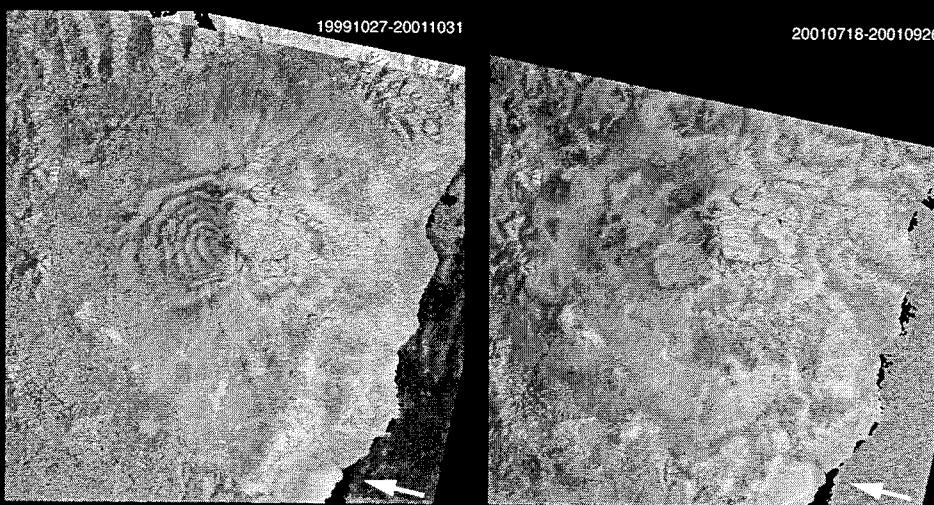
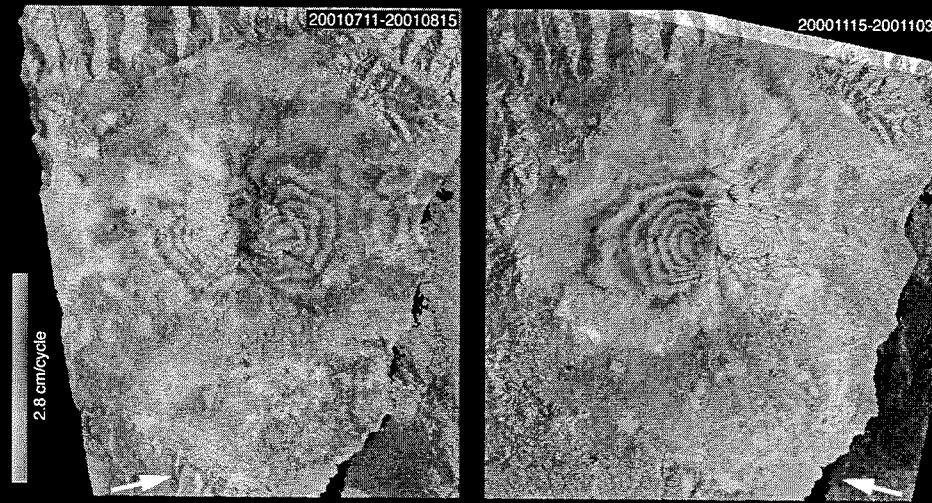


Field, seismological and GPS provide an initial framework for the eruption.



Observations from the INGV Catania
(EOS Dec. 25, 2001)

July 18 - August 9, 2001 flank eruption



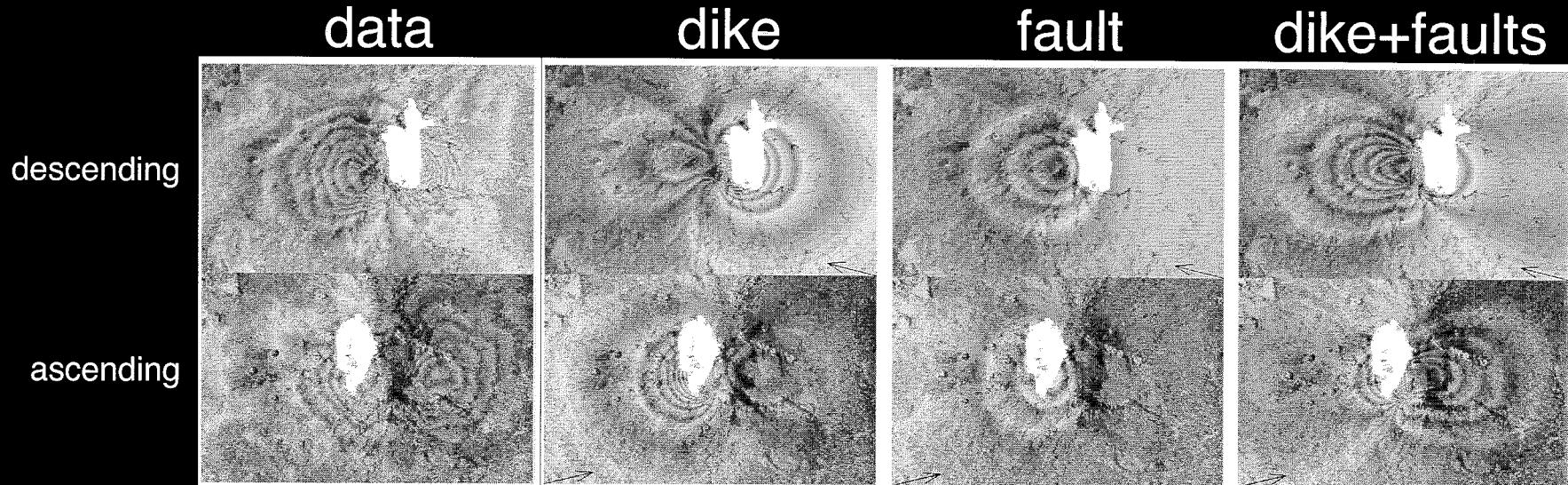
1999.8

2001

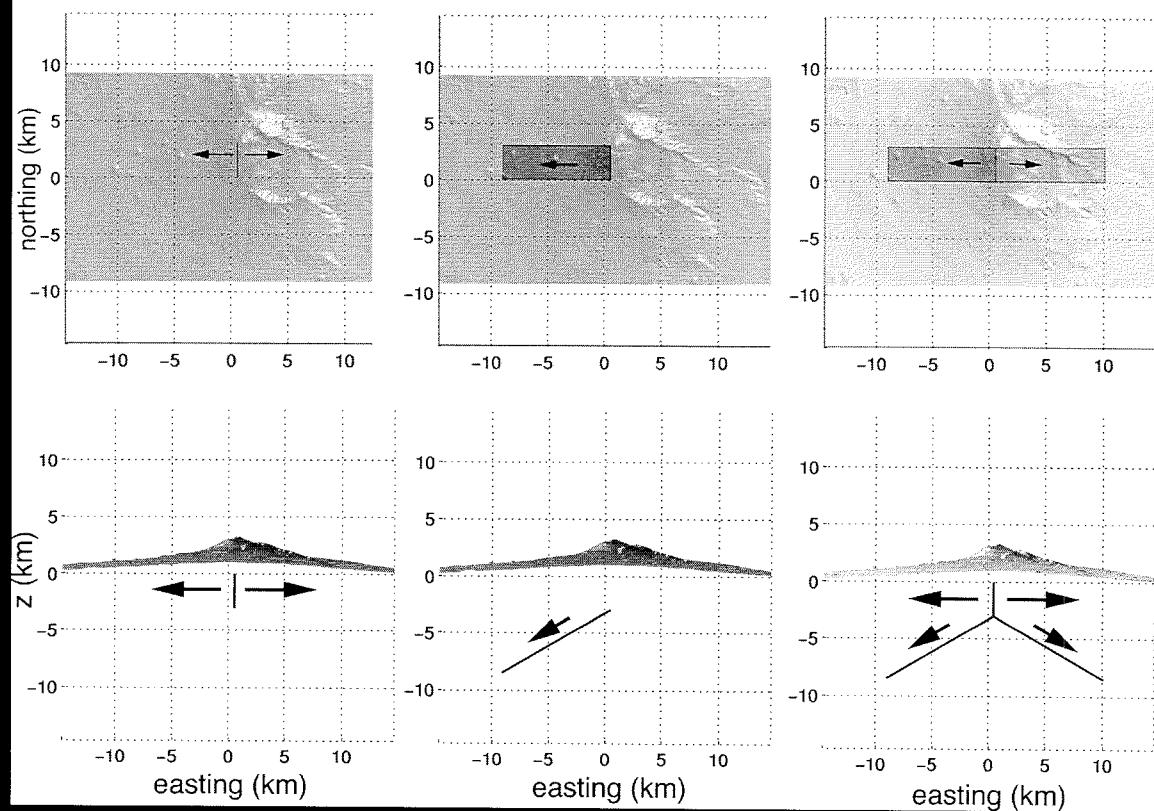
eruption

2002



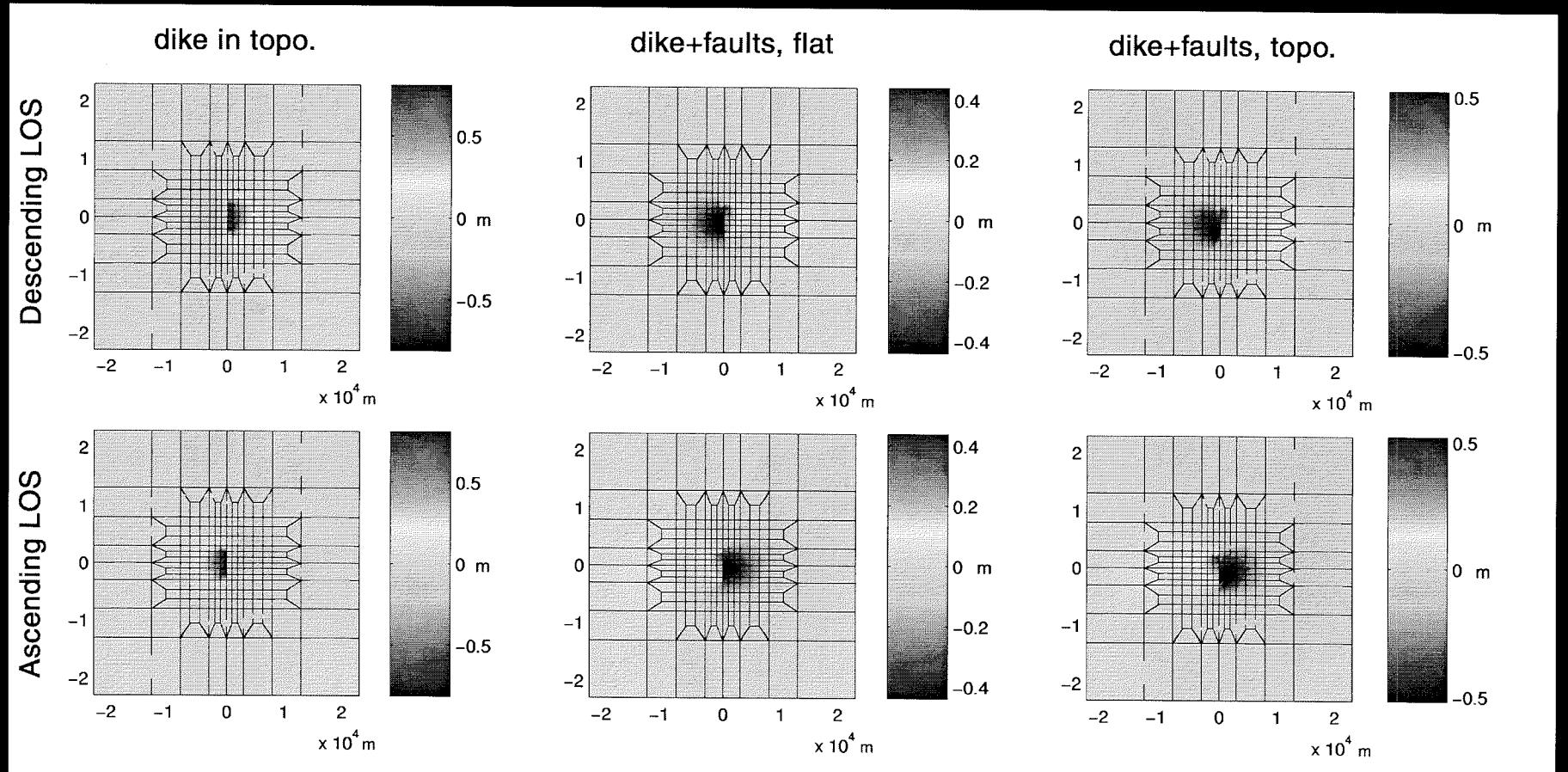


How do we explain the observed deformation?



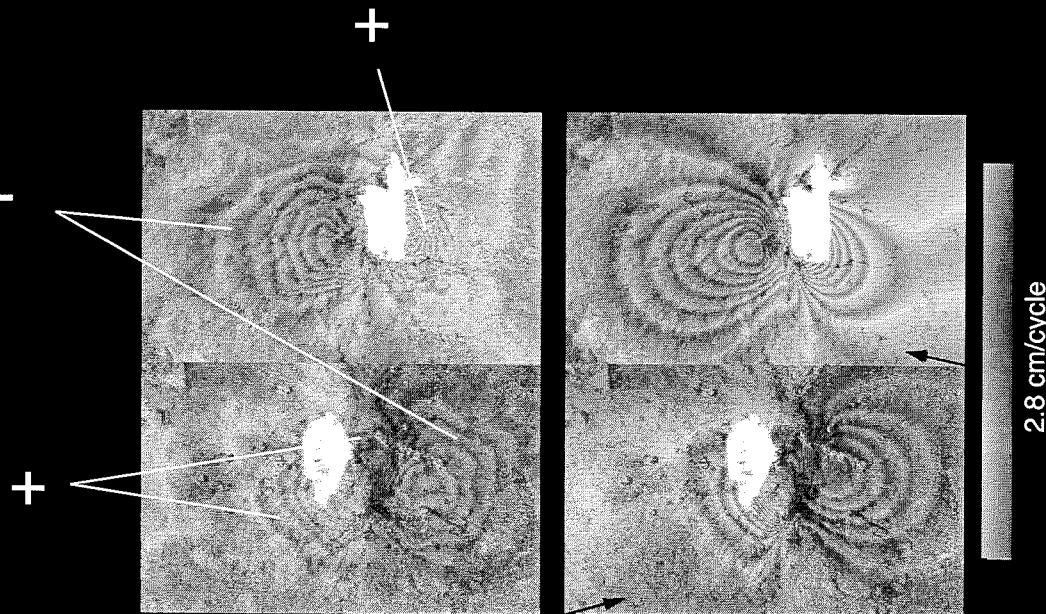
What about effects of topography on the deformation?

3D finite element models for either a flat or with topography

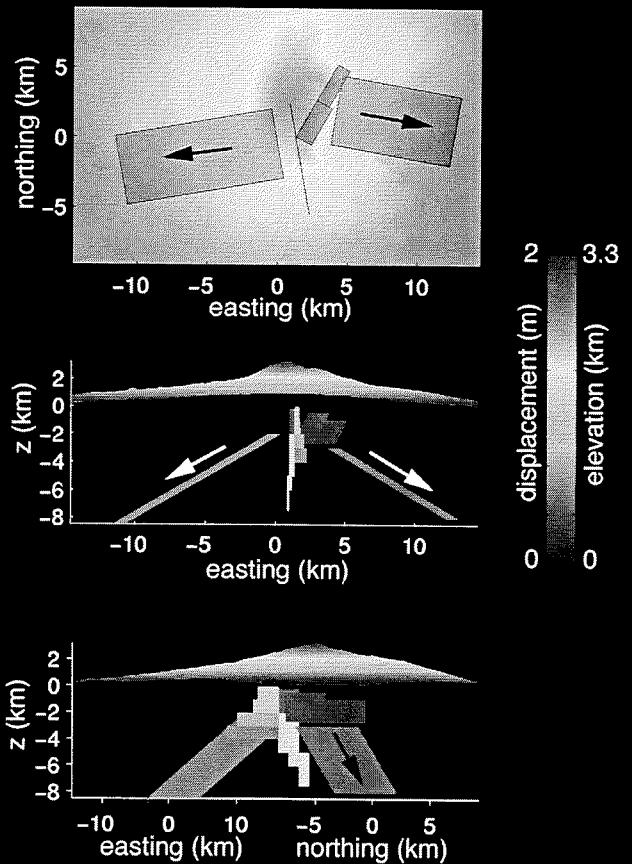


Shallow dike + faults \approx dike + faults in the volcano edifice.

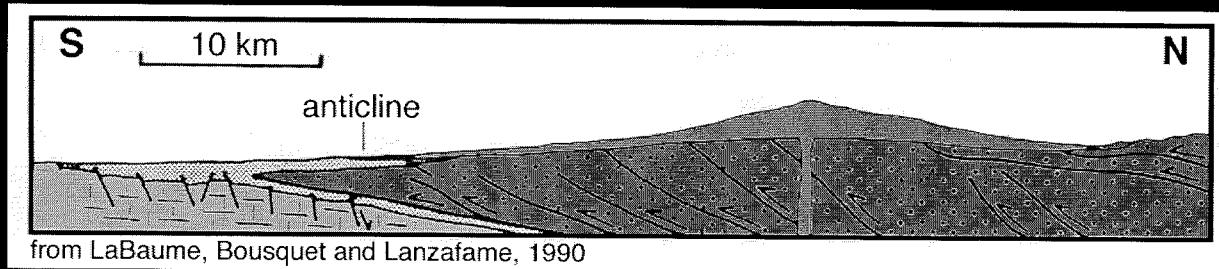
Complex half-space model



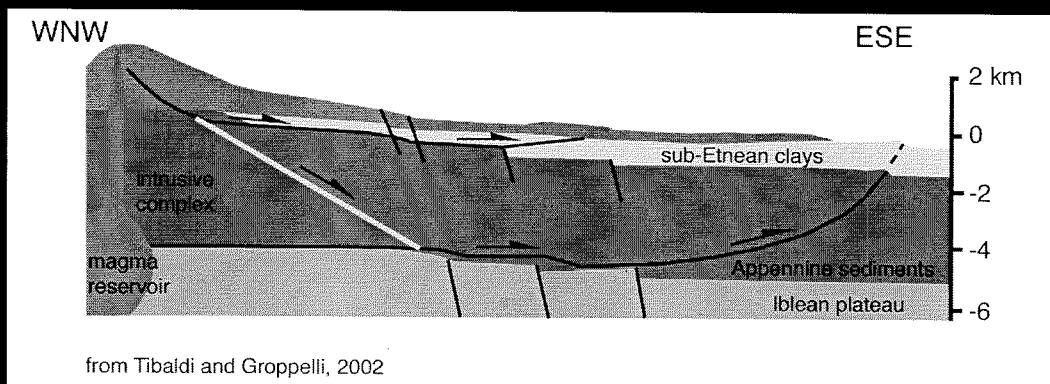
Broad **negative** LOS displacements constrain shallow normal faults. **Positive** LOS displacements constrain dike structure.



How does this fit with structure models?



- NS seismic profile shows Etna lying on top of older sediments.
- Clay layer seen as possible slip horizon.

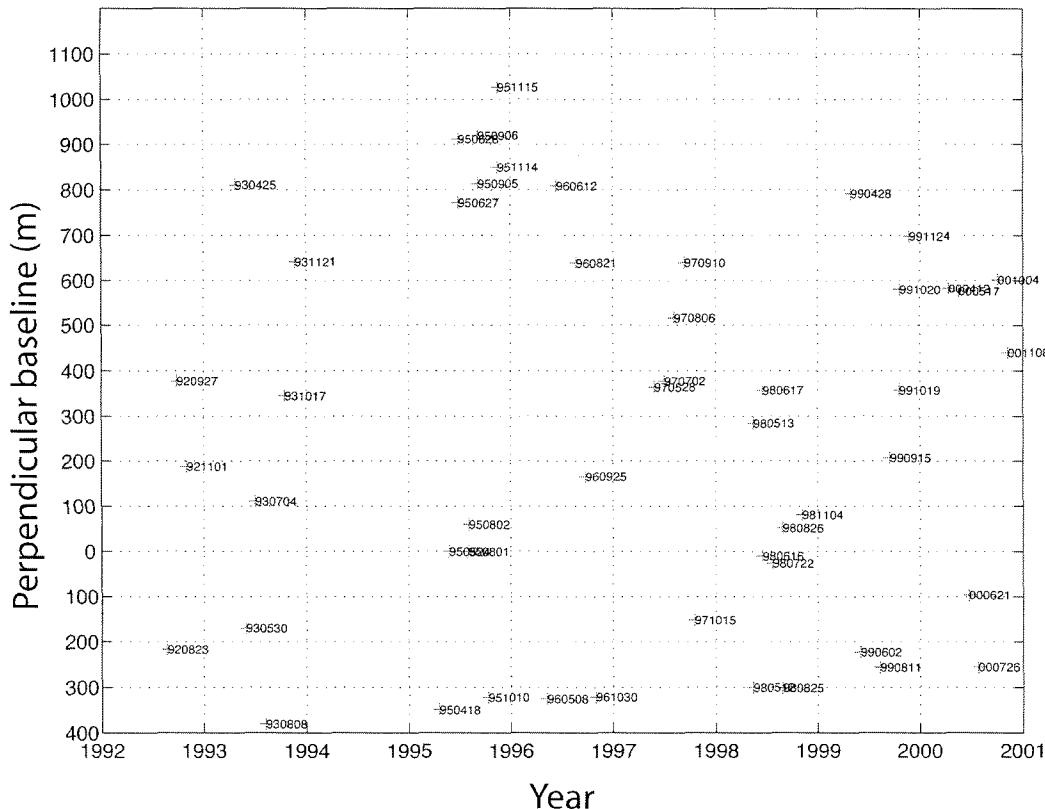


- EW profile based on surface structure and offshore seismics.
- Accommodates E flank motion.

InSAR based model does not fit previously recognized structures beneath W flank.
Nor does it fit InSAR observations of volcano flank motions.

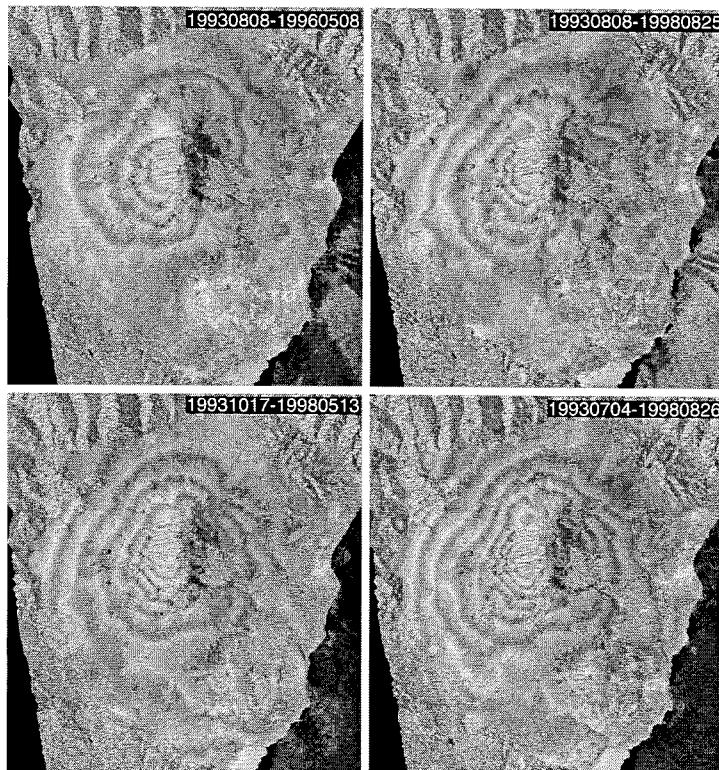
InSAR time series analysis

How do we integrate a large number of interferograms?



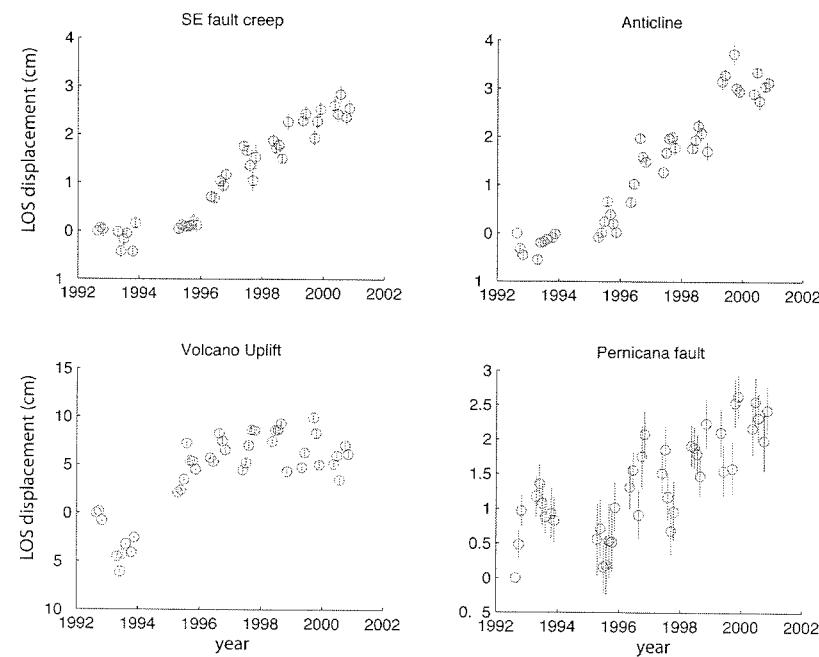
Problem: InSAR requires baselines be 100-200 m maximum. But the ERS orbit varies over more than 1500m.

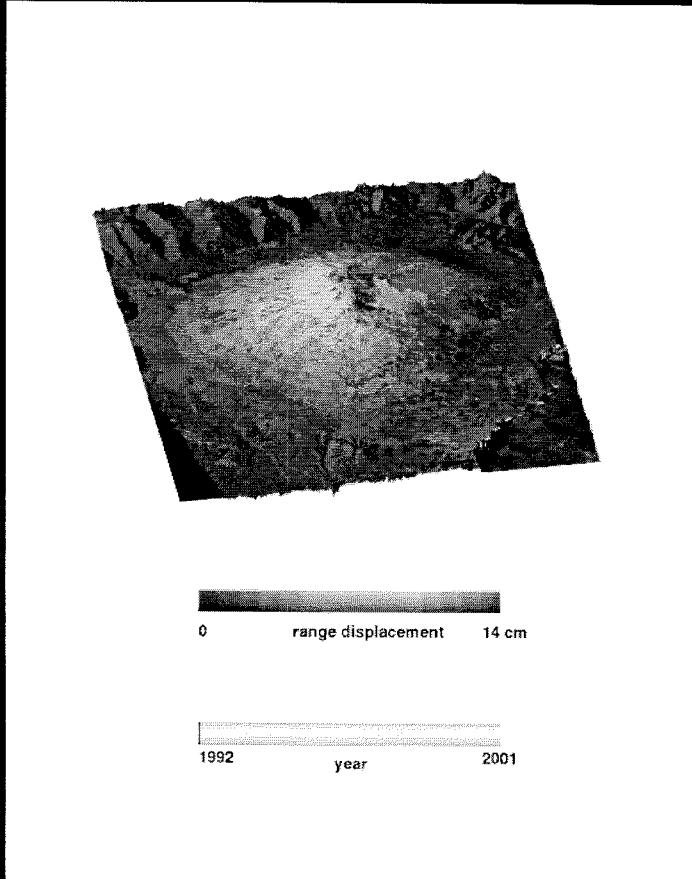
Solution: we use a damped least-squares inversion to solve for the displacements at each SAR acquisition relative to a reference image [Berardino *et al.*, 2002]. This gives us an InSAR time series.



Observed differential interferograms suggest *inflation* and *flank motion* of Etna over various intervals during the 1993-1998 time period.

Inversion of more than 100 interferograms for a time series of 47 dates from 1992-2000 is shown below.





Conclusions

- InSAR observations of Etna demonstrate its ability to magmatic and structural activity. Some of which would be difficult without its detailed coverage.
- InSAR observations of the 2001 flank eruption require a combination of dike and symmetric splitting over shallow normal faults.
- Activation of the west-dipping fault and the relative symmetry of the slip suggests that on the short time scale of the dike intrusion Etna deforms without regard to its long-term flank motion.

Future direction ... InSAR time series to better understand magmatic-structural interactions.